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Wis DOT RD&T

from research to reality BRIEF

RESEARCH DEVELOPMENT & TECHNOLOGY TRANSFER

Field Measurement of Water-Cement Ratio

The water-cementitious material (w-cm) ratio of concrete – the ratio of free water to cementitious material, by mass – governs concrete paste porosity, a key to determining the final strength of concrete pavement. Conventional theory holds that the higher the w-cm, the less compressive strength and durability the concrete offers.

What's the Problem?

Currently, pavement engineers extrapolate w-cm determinations from batch mix sheets – recipes for how much water and concrete materials will be combined for the pour. Because environmental conditions, moisture contents of aggregates, and batch mixing irregularities weaken the reliability of batch sheets for determining w-cm, WisDOT staff and industry both sought a real-time field assessment of w-cm for accurately projecting finished strength. Such an assessment might provide a quality control measure that could be used to make real-time adjustments to the construction process.

Research Objectives

In this study, investigators tested the microwave oven and Troxler 4430 Water Cement Gauge in the field to determine:

- Accuracy in w-cm determination
- Accuracy in predicting concrete strength

Both methods were examined in a previous laboratory phase of research and found to be promising in terms of accuracy and usability. Multiple tests of both tools were conducted on 46 concrete batches at seven sites in the field. Nuclear gauge calibrations based upon laboratory data were also tested. Investigators evaluated the instruments by comparing standard and mean errors achieved in laboratory and field findings. A maximum acceptable error threshold of 0.01 to 0.02 was sought for field test efficacy.

Research Results

Accuracy of Microwave Method. This method determines the water mass of a 1500-gram fresh concrete sample from a pour site by heating out the available water, and comparing the weight after heating to that before. Comparing this differential to batch mix sheet reports of the amount of concrete material yields a w-cm.

Irregular moisture content in plant-stored aggregates complicated the testing process, leading to field recoveries of over 100 percent of the moisture reported in plant batch sheets. Moisture contents in batches of plant-stored aggregates were found to vary hourly throughout a day and throughout a pile, a variation not accounted for in plant reports. This variation, considered with batch mixing and sampling size errors, accounts for irregular water mass readings.

Field standard errors ranged from 0.026 to 0.072, with an average of 0.037, exceeding the 0.014 to 0.030 levels and 0.027 average of lab tests.

Based on earlier findings that the results of multiple samples, when averaged, produce more accurate w-cm figures than single samples, investigators expect repeated tests of field batches to yield minimum standard errors of 0.02. Microwave testing produced more accurate field w-cm figures than did mix report extrapolations. The microwave method, then, reliably measures w-cm of fresh concrete in the field, particularly when multiple samples are used.

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Water-cement testing was carried out at seven concrete paving sites in Wisconsin during the summers of 1999 and 2000. Two sites were located in Fond du Lac County.

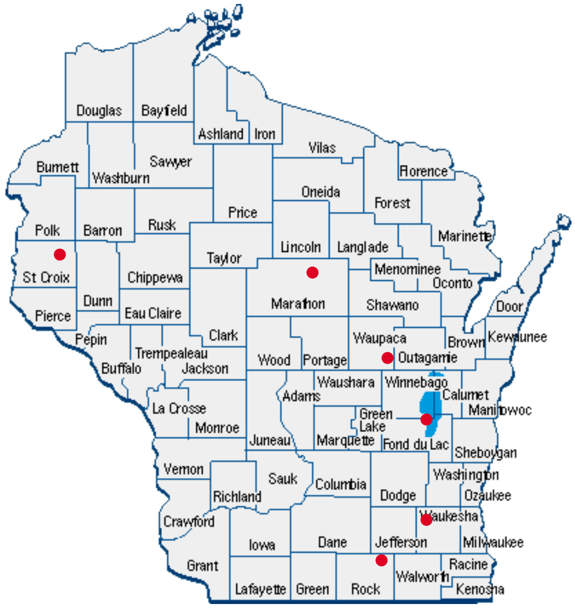

Figure 2-1: Concrete Paving Sites Visited

Accuracy of Nuclear Gauge Method. The Troxler Water-Cement Gauge employs two probes – one measuring water content by counting how many neutrons emitted from californium-252 are thermalized by the hydrogen in the cement's water content, the other measuring the number of photons emitted from americium-241 that are absorbed by calcium and other cement components. Combined results determine w-cm.

Factors that influence probe counts include air content of mixes, levels of igneous aggregates, and calcium content of fly ash. To accommodate these factors, investigators tested calibration methods, dismissing the ineffective.

Field test errors showed less variation between limestone and igneous-rock aggregates than did lab tests, from 0.042 to 0.064 for limestone, and 0.012 to 0.089 for igneous rock. However, the combined w-cm range for nuclear gauge field tests was wider than in lab tests, due to varying moisture content in batch aggregates, gauge measurement difficulties, and errors inherent in the instrument.

With limestone aggregates, investigators showed the nuclear gauge capable of w-cm determinations with errors within 0.01 of the mean, after calibration, but only in the lab. Field applications have not reached this standard, and the study produced no data suggesting better field performance was likely. The gauge proved insufficient for measuring w-cm of igneous rock in the lab or the field. Together, the nuclear gauge's unsuitability for igneous aggregates, poor field performance with limestone aggregates, and extensive training and certification procedure for operators render it ill suited for field use.

"This study demonstrated that accurate measurement of the water-cement ratio in the field is very difficult to achieve. And the relationship to ultimate pavement strength is not there... at least at this time."

- David Larson, WisDOT Pavements Section

Strength Predictability. Batch reports proved less useful in predicting w-cm than did the two tested methods. Researchers subjected compression cylinders drawn from each tested pour to compression tests. Field w-cm data from the microwave and nuclear gauge methods more accurately predicted finished concrete strength than did the batch plant mix reports, yet none of the methods produced reliable results.

Investigators, then, could recommend neither microwaves nor Troxler nuclear gauges for predicting finished concrete strength in the field based upon w-cm determinations.

Benefits

This study narrows the field of possible methods for determining finished concrete strength by measuring the w-cm of a fresh pour. Neither the microwave oven nor the nuclear gauge could usefully predict strength.

However, the study finds that microwave ovens can reliably measure the w-cm of fresh concrete in the field, though at this time the nuclear gauge cannot.

The study also demonstrates the problematic nature of determining w-cm based upon concrete batch mix reports from plants. The variability of the moisture content of plant-stored aggregates hinders on-site determination of w-cm and renders batch mix reports unsuitable for predicting finished concrete strength.

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